STIMULATED EMISSION OF RADIATION FROM GaAs *p-n* JUNCTIONS*

Marshall I. Nathan, William P. Dumke, Gerald Burns
Frederick H. Dill, Jr., and Gordon Lasher

International Business Machines Corporation
Thomas J. Watson Research Center
Yorktown Heights, New York

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A characteristic effect of stimulated emission of radiation[1] in a fluorescing material is the narrowing of the emission line as the excitation is increased. We have observed such narrowing of an emission line from a forward-biased GaAs *p-n* junction. As the injection current is increased, the emission line at 77°K narrows by a factor of more than 20 to a width of less than $kT/5$. We believe that this narrowing is direct evidence for the occurrence of stimulated emission.

The GaAs junctions used in this experiment were made by diffusing Zn into GaAs doped with Te. These diodes were bonded onto a Au-plated kovar washer and the junction was etched to an area of approximately 1×10^{-4} cm^2 as shown in the inset of Fig. 1.[2] No attempt was made to obtain highly resonant electromagnetic modes. The diodes were immersed in liquid nitrogen and driven with current pulses as short as 50 nsec at high current levels. The light output was measured using a Perkin Elmer grating spectrometer and a Dumont 6911 photomultiplier.

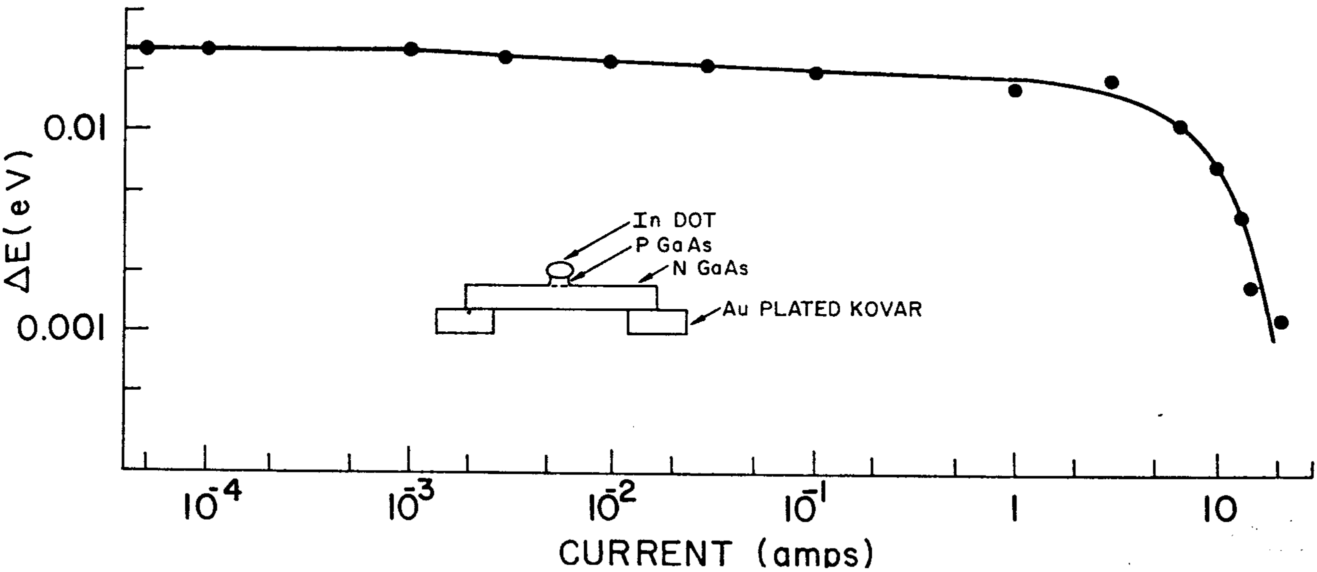

Fig. 1. Full line width at half maximum intensity vs injection current. The area of the diode is 1×10^{-4} cm^2. The inset shows the geometric configuration of the diode.

At low injection levels, it was observed that more than 95% of the light was emitted in a line at 1.47_3 eV with a width at half maximum of 0.026 eV. From photoluminescence experiments we believe the observed line is due almost entirely to transitions between the conduction band and a Zn acceptor level. It has been theoretically shown that such transitions give rise to a relatively short radiative lifetime for holes trapped by the acceptors.

The quantum efficiency per injected electron was greater than 0.2 and perhaps close to 1 for currents greater than 10 A/cm^2. Similar results have been reported by other workers.[2-4] However, unlike the previously reported measurements,[2] we observe constant quantum efficiency for currents greater than 10 A/cm^2.

As the current was increased the half width decreased, at first only slightly, but at currents of 10^4 to 10^5 A/cm^2, the narrowing was striking, as can be seen in Fig. 1.

At high current densities heating of the *p-n* junction, due to its series resistance, causes a shift of the bandgap and, therefore, a shift of the emission line during the duration of the pulse. This shift results in an overestimation of the half-width of the line at currents above 10 A. The line-width values given for currents above 10 A represent only upper limits. In one diode, at the highest currents used, the emission line was resolvable into two lines approximately 6 Å apart and 2 Å wide.

The plausibility of stimulated emission in a *p-n* junction may be appreciated from a simple calculation of the ratio of the number of photons which in the steady state must be present in the crystal to the number of electromagnetic modes within both the crystal and the emission line. If one considers the relationship between the intensity of light emission from the crystal and the density of photons in the crystal, taking into account internal reflection effects, it can be shown that, at a current density of 10^5 A/cm^2, a quantum efficiency of 0.5, and a line width of 0.02 eV, there are 100 photons per electromagnetic mode. With such a photon population radiative emission would be almost entirely stimulated. Narrowing of the emission line and geometrical mode selection would yield a larger photon population per mode but in a fewer number of modes.

The fact that the quantum efficiency is relatively constant for current densities at which the line width narrows rapidly (it is presumed that the photon occupation number of the reinforced modes increases rapidly) is evidence that the quantum efficiency is close to 100%.

The presence of stimulated emission probably has an effect on the high frequency characteristics of the diodes. Under conditions giving high photon occupation numbers, the response time of the diodes should be even smaller than those already reported.[2]

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